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TECHNICAL NOTES

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No. 553

NOTES ON THE TECHNIQUE OF LANDING AIRPLANES

EQUIPPED WITH WING FLAPS

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Washington
January 1936



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SUMMARY

The proper landing of airplanes equipped with flaps, although probably no more difficult than landings without them, requires a different technique. The effects of flaps on the aerodynamic characteristics of a wing are given and, with the aid of figures and diagrams, a detailed comparison of the glide and landing of an airplane with and without flaps is made. The dangers attending improper execution and the importance of such factors as air speed, fuselage attitude, glide-path angle, and control manipulation, upon all of which a pilot bases his judgment, are emphasized.

Of most importance in connection with the use of flaps are: The maintenance of a sufficient margin of speed above the stall; a decisive use of the controls at the proper time; more cautious use of power during the approach glide; and, above all, the willingness to accept the steep nose-down attitude necessary in the glide resulting from the use of flaps.

INTRODUCTION

The detailed technique of making a landing in a normal airplane is well known to all pilots. The landing of an airplane equipped with wing flaps, however, is accompanied by certain differences in technique that are not so well known. Of course, there are many pilots who, by first flying airplanes equipped with flaps of small effectiveness, have had an introduction to them and an opportunity to adapt themselves to the differences before flying very effective flap installations; but there are others who, having had no previous experience with flaps, may be called upon to fly an airplane equipped with a very effec-

tive flap installation. It is for the benefit of these pilots that these notes, giving an analysis of the conditions existing during an approach glide with and without flaps, have been prepared.

NORMAL LANDINGS WITHOUT FLAPS

The landing of a conventional airplane may be considered as consisting of the three phases illustrated in figure 1-A; gliding down to the field, leveling off the flight path until it is horizontal, and decelerating until the lift, which can no longer be maintained constant by increasing the angle of attack, becomes insufficient to support the weight and the airplane settles to the ground. The lowest gliding speed is that for which the reserve lift is sufficient for the leveling-off process; or, if the airplane is very clean and not much reserve lift is required, the glide is limited by the loss of aileron effectiveness or by the pilot's feeling of security concerning a possible stall brought on by a gust. All pilots have probably experienced the condition of gliding so slowly that the air speed is reduced below the speed at which reserve lift is available and with most of the elevator control used; so that the tail could not be lowered nor the vertical velocity checked, a condition resulting in a hard two-point landing. Leveling off requires energy that comes as a result of the excess speed carried in the glide. Aside from the limitations set by the loss of aileron effectiveness and the possibility of inadvertently stalling, if the correct speed were carried in the glide the stall would be attained just at the completion of the leveling-off period and the airplane would immediately settle to the ground. In practice, both for the preceding reasons and because it gives the pilot a certain leeway, a greater speed than that required for leveling off is carried in the glide so that the airplane is leveled off at some speed above the stalling speed and permitted to decelerate in level flight just clear of the ground.

An airplane is normally constructed so that its attitude when at rest on the ground approximates that at the stall and therefore the airplane settles to the ground in the correct three-point attitude at the end of the deceleration run. In the case of an average conventional airplane the drag is fairly high and the deceleration of the airplane rapid so that not much distance is required after

leveling off and the manipulation of the elevator is not very critical. For a very clean airplane the drag is low, the airplane decelerates slowly, and considerable distance is used in the deceleration run. The manipulation of the elevator is critical because if the tail is lowered by too coarse a movement the airplane may climb rapidly to an appreciable height before flying speed is lost. Thus the required fine adjustment of the elevator increases the difficulty of making a three-point landing in a clean or "floater" airplane.

LANDINGS WITH FLAPS

Landings with flaps are not necessarily more difficult to execute than are landings without flaps. For best results they must be made in a different manner, however, with a thorough appreciation of the factors involved. For that reason they will be treated in more detail.

Purpose of flaps.-- Wing flaps are used on an airplane to steepen the glide-path angle, to reduce the landing speed, and in some cases to aid the take-off. The effectiveness of flaps depends upon their type, their area compared with that of the wing, their location on the wing, the amount they are deflected, and their effect upon the stability and control characteristics of the airplane. Thus it is apparent that the degree of effectiveness of the flaps depends upon the particular airplane design; in general, however, their characteristics remain similar.

Effect of flaps on landing.-- The effect of flaps on the landing characteristics of an airplane is well illustrated by an installation of full-span Zap flaps on a Fairchild 22 airplane for which complete data are available. Figure 2 shows the lift and drag characteristics of the airplane as a function of angle of attack as determined in flight with flaps both up and down. Of principal interest are: The increase of the maximum lift coefficient from 1.47 to 2.27, which for this airplane corresponds to a decrease in the minimum or stalling speed of from 50 to 40 miles per hour; the shift in the entire lift curve so that the same lift coefficient, and consequently the same speed, occurs at about 13° lower angle of attack with the flap down than with it up; the occurrence of the stall at practically the same angle of attack; and the proportionally greater increase in the drag than in the lift, which accounts for the steepening of the path angle.

in a glide with flaps down. The effect of the flaps on the gliding characteristics of the airplane is shown more clearly in figure 3, which gives the glide-path and attitude angles. The Zap flap is very effective in changing the glide-path angle and it will be noted that the flattest glide (13°) that can be maintained with the flaps down is steeper than any glide that can be maintained with the flaps up at speeds up to 110 miles per hour.

The attitude angles show an even greater change than do the glide-path angles. The airplane can be glided at the stall with the flaps up and the nose 7° above the horizontal; whereas, with the flaps down, the nose can never be held above 2° . At the same speed the difference in attitude equals approximately the change in angle of attack for the same lift coefficient plus the change in glide-path angle, which, for 50 miles per hour, equals 19.8° .

Normal landings with flaps.- Good landings for the F-22 airplane with the flaps up and down are shown in figures 1-B and 1-C. In the normal landing with flaps up a speed of 60 miles per hour is carried during the glide. The glide path at this speed is 6° below the horizontal; the angle of attack is 7.3° ; and the nose of the airplane is slightly above the horizontal with an attitude angle of 1.3° . Leveling off is accomplished in a normal manner and, since the airplane is of average cleanliness, it decelerates fairly rapidly and settles to the ground after a reasonably short level-flight run. Contact is made at practically the stalling speed of 50 miles per hour in a three-point attitude. Thus, from the steady glide attitude, the nose has been raised through an angle of 11.7° to the landing angle of 13° . Further, an attitude of 13° for landing is 6.2° greater than the attitude in a steady stalled glide! If, for a moment, it is supposed that at the instant of reaching the 13° attitude and 50-mile-per-hour stalling speed, the airplane were 15 or 20 feet in the air instead of just off the ground, it is apparent that in the ensuing path to the ground the nose must fall.

In figure 1-C with the flaps down, 50 miles per hour should be carried in the glide. In this condition the glide-path angle is 13.7° below the horizontal, the angle of attack is 0.8° , and the attitude is nose down 12.9° . The significance of the nose-down attitude should be fully appreciated. By reference to figure 3, it will again be noted that with the flap up a nose-down attitude of equal magnitude is not attained even in a dive at speeds up to

110 miles per hour. Therefore, in an approach to a three-point landing with this flapped airplane, the pilot must be prepared to put the nose down to an angle greater than he would associate with a fairly high-speed dive without flaps.

The attitude in the three-point landing position is, of course, the same with the flap down as up so that with the flaps down during the leveling-off process the fuselage must be rotated (or the nose raised) through an angle of from -12.9° to 13° , or 25.9° , as compared with 11.7° , flaps up. The attitude of 13° for landing is 12.3° greater than is possible in a steady stalled glide! If the pilot starts to level off at the same height above the ground with flaps down as he would with them up, the maneuver must be made more abruptly because of the greater changes required in the flight path and attitude, and because there is less time available owing to the increased vertical velocity. An alternative that might be attempted is to start leveling off at a higher altitude than that shown in figure 1-C. This procedure is dangerous, however, because with its high drag the airplane decelerates rapidly and the altitude from which the airplane levels off is critical. The floating is practically negligible and the airplane settles to the ground almost immediately after leveling off. Thus with flaps down there seems to be a greater chance of poor judgment in the leveling off, which would result in a two-point landing.

Incorrect landings with flaps.— Figures 1-D and 1-E illustrate incorrect landing technique where the pilot attempts to maintain the same attitude with the flaps down as he would normally have with them up. In figure 1-D it is assumed that the pilot makes the approach on the basis of attitude rather than air speed. In the closest approach to the flap-up attitude, the airplane with flaps down will have a speed approximately equal to the stalling speed, or 40 miles per hour. The glide path is no steeper than when the correct speed of 50 miles per hour is carried (fig. 1-C). The vertical velocity will be slightly less because of the lower speed. When the airplane approaches the ground, however, there is no excess lift available for leveling off and contact will be made with the attitude and vertical velocity of the glide. The use of any remaining elevator is, of course, ineffective, except actually to stall the airplane and to make a slight change in attitude.

Consider what actually happens if the pilot does attempt to use the elevators to get the tail down. First, and most important, if the elevator movement is made too soon, the airplane will stall while still high enough off the ground for the lift to break down, the nose to drop, and the speed to pick up; if the airplane should have vicious stalling characteristics, it may in addition whip over on a wing. Under any conditions the best that can be hoped for is a two-point landing.

If the elevator is not moved, or is moved too late to take effect, the airplane will settle to the ground before any of these things have time to occur. Even with the most adequate elevator control an airplane cannot be put much more than 5° beyond the stall so that it is impossible to change the attitude the 12.3° required to get the tail down at contact. It is appreciated that a pilot is not likely to approach the ground at the stall, as in the case illustrated, even if he wished to and did raise the nose somewhat during the glide and that, in an actual case, some compromise in speed between 40 and 50 miles per hour would result. In any event, however, until the speed is increased to at least 50 miles per hour, the pilot will not be able to level off the path completely before contact and there will be no assurance that the airplane could be landed in a three-point attitude even with what would normally be considered adequate elevator control.

Figure 1-E illustrates the use of the throttle to hold the nose up, during the approach glide, to about the same attitude as in the glide without flaps and with the proper excess speed. This type is known as a "power-approach" landing and under certain circumstances it is very useful, especially for passenger comfort in transport airplanes. The steep path in the glide, one of the important advantages of flaps, is thus eliminated but the advantage of the reduced landing speed is maintained. Stretching a glide by short-period applications of power is considered as another case and will be discussed later. The power-glide approach is incorrect only when it is used, as in the present case, to avoid certain natural consequences of the use of flaps without appreciation of the factors involved. From the time the throttle is cut, the principal difference between an airplane without flaps and one with flaps in this type of landing is in the time and distance elements. Because of the high drag the airplane with flaps will lose flying speed faster, "whipstall" sooner, and nose down through a greater angular range than

the one without flaps; consequently, the throttle should be cut when the airplane with flaps is closer to the ground.

Figure 1-E shows the sequence of events if the throttle is cut too high above the ground, yet not high enough to allow nosing over to gain speed. After the throttle is closed, the stick can be pulled back and the vertical velocity momentarily arrested by a change in attitude. If the airplane contacts the ground at this time, the landing is satisfactory. Once the flight path is level, however, even if the airplane is not stalled, it will decelerate rapidly and nose down to attain the equilibrium glide for the air speed and angle of attack, which will be as shown in figure 1-D, with a glide-path angle of 13.8° . Actually the flight path will momentarily pass beyond that value and the airplane may contact the ground in a more nose-down attitude and with a high vertical velocity. Inability to check the nosing-over condition that results after power is reduced in a power-approach glide by the full use of any remaining elevator might erroneously be assumed to indicate insufficient elevator control; whereas the ability to stall the airplane in a steady glide, power off, flaps up or down, is a criterion of their effectiveness. The height above the ground at which the throttle should be cut for this type of landing depends on the particular airplane and flap and should be found by practice. It will be considerably less than the height at which the throttle could be safely cut on an airplane without flaps.

Stretching a glide by means of short-period applications of power is the condition most likely to lead to trouble. Most pilots periodically apply the throttle momentarily during a glide to assure that the engine will respond if needed. In the normal airplane without flaps the small change in attitude, if allowed to occur, is not critical. Usually, however, the small increase in speed resulting from a slight elevator movement to counteract a possible attitude change is accepted as a safety factor; a similar procedure would be regarded as good practice for an airplane with flaps.

Consider the case in which the pilot is in a slow, steep, steady glide as in figure 1-C and, when at an altitude of 400 or 500 feet, decides that he is undershooting the small area in which he has decided to land. The flight path must be flattened. The application of power and a change of attitude result in a condition such as assumed

at the start in figure 1-E. It is soon realized that, if this power approach is maintained, the field will be over-shot, so the power is reduced. If at that instant the airplane is just off the ground, a landing can be made. Thus the pilot has used the power to stretch the glide and assist in changing the attitude for landing. If, however, the landing cannot be made at that instant, it should be appreciated that the steady-glide condition that must be obtained is again the original glide condition as shown in figure 1-C. In order to make the transition to this glide quickly and with as little loss of altitude as possible, the pilot must force the airplane into the correct nose-down attitude; otherwise there may be an immediate loss of speed, a slow natural steepening of the flight path, and contact with the ground as shown in figure 1-E. It should be mentioned that the vertical velocity in this final condition cannot always be alleviated by full-power application just before contact, although it may be possible to obtain the correct attitude for landing in contrast to what can normally be done on an airplane without flaps.

CONCLUSION

1. At least as much excess speed above the stall should be carried in a glide to a landing for an airplane with flaps down as with flaps up if a three-point landing with no vertical velocity is to be made.
2. The airplane with flaps should be well nosed down during the approach, probably as much as is usually associated with a fairly high-speed glide without flaps.
3. The leveling off of the approach glide must be more abrupt with flaps than without them because of the greater required change of attitude angle and flight path to get in position to make a three-point contact.
4. In a steady power-approach glide to a landing, the throttle of the airplane with flaps should be cut when the airplane is considerably closer to the ground than for the airplane without flaps.
5. When short bursts of power to stretch a glide are used, the throttle should be closed at a sufficiently high

altitude to allow the original steep glide path to be resumed before leveling off, unless the power is used to assist in checking the vertical velocity.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., January 10, 1936.

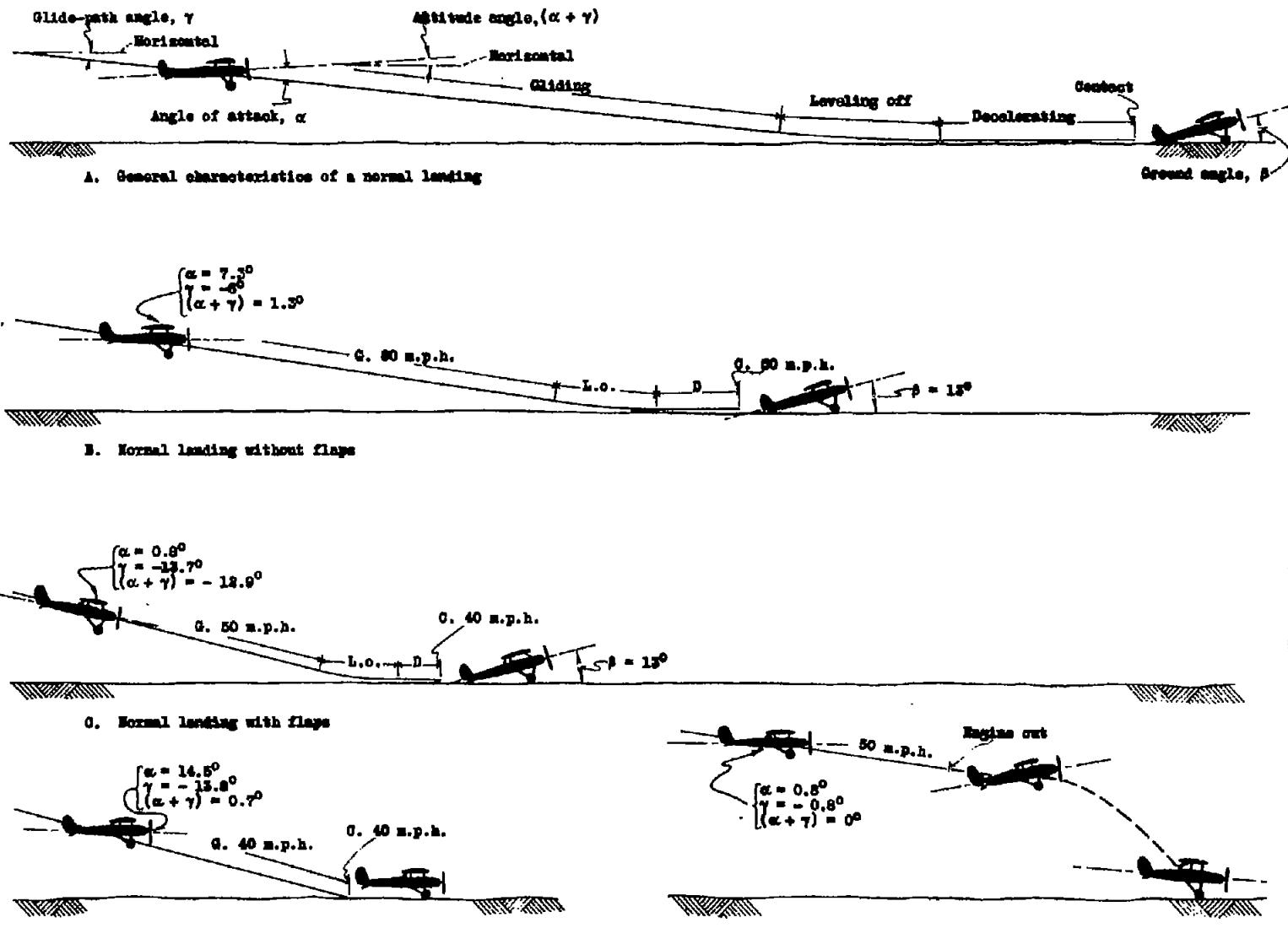


Figure 1. - Comparative landings of airplane with and without flaps.

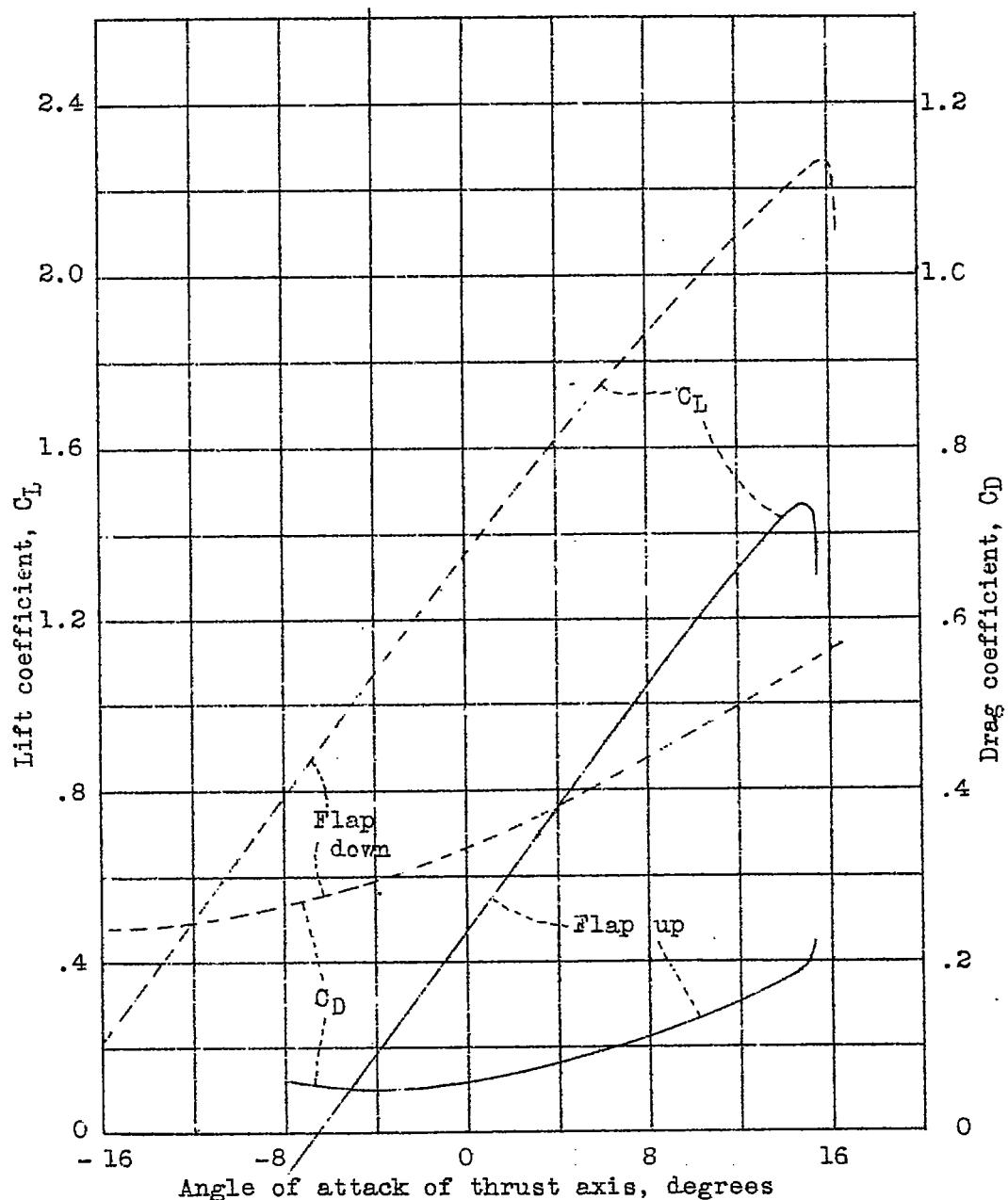


Figure 2.- Lift and drag characteristics of a Fairchild-22 airplane with a Zap flap.

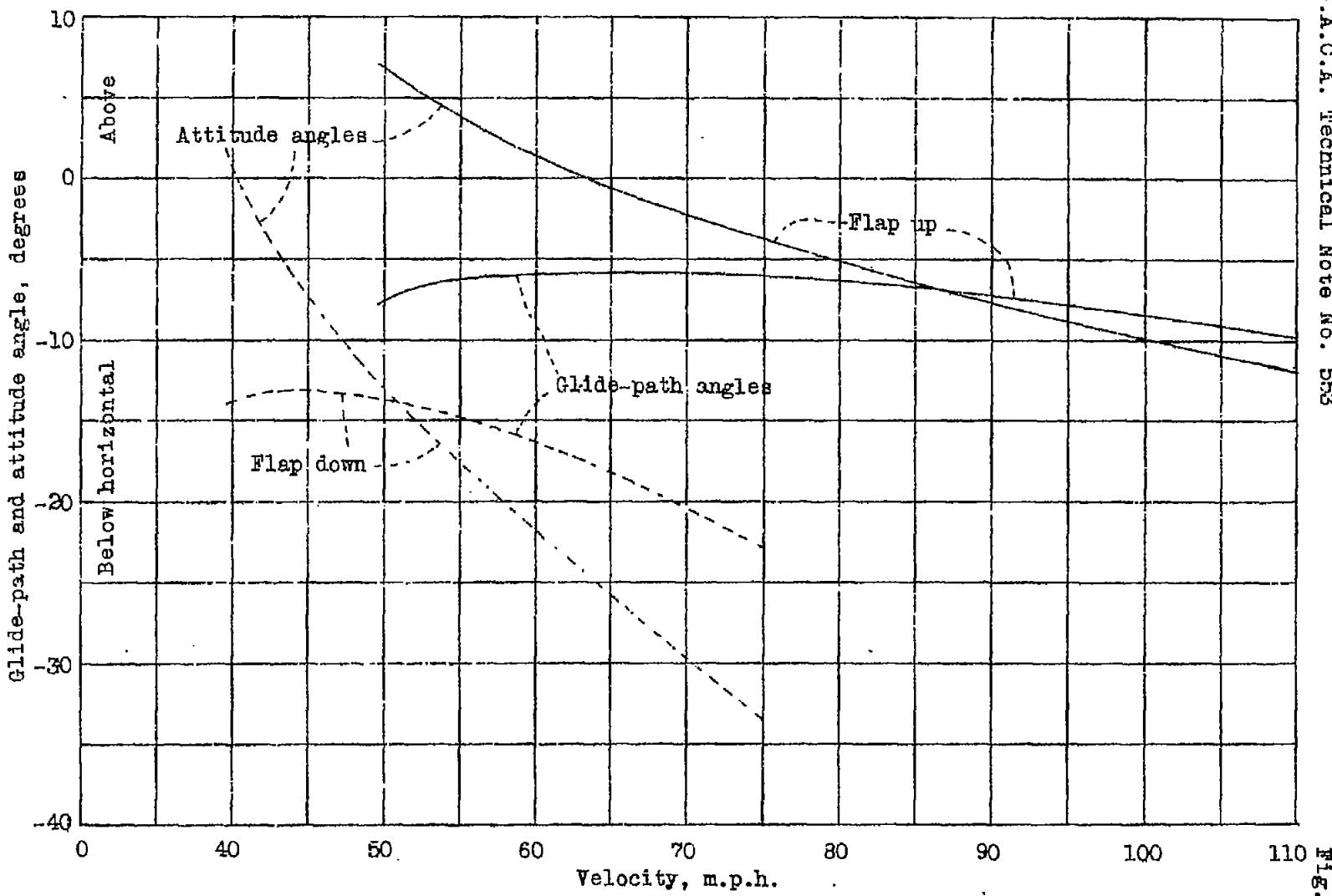


Figure 3.- Glide-path and attitude angles of a Fairchild-22 airplane with a Zap flap.